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# Nozzle and Carrier Application Effects on Control of Soybean Leaf Spot Diseases

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# Nozzle and Carrier Application Effects on Control of Soybean Leaf Spot Diseases

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***Abstract***. *A two-site, two-year field application experiment investigated fungicide coverage in a fully-developed soybean canopy. Application treatments included "high-rate" (187 l/ha; 20 gal/acre) and "low-rate" (112 l/ha;12 gal/acre) with fine-droplet two-orifice tips, medium-droplet two-orifice tip at 187 l/ha (20 gal/acre), a coarse-droplet single-orifice "herbicide-style" tip at 168 l/ha (18 gal/ac), and an air-assisted spray treatment. Droplet coverage and size, and foliar disease severity in the lower, middle, and top parts of the plant canopy, and crop yield were measured.*

*Droplet size generally followed expected manufacturer specifications. Percentage area covered and drops/cm$^2$ were significantly less in lower parts of the plant canopy (1 – 8%) than in the canopy top (15 – 18%). Coverage was affected less by application treatment and differences observed in pooled data from all canopy locations were mixed. Although smaller droplets usually produced increased drops/cm$^2$, percentage coverage did not always increase. In the second year coverage improved with medium droplets. Foliar disease pressure was light so that yield or disease severity was little affected by application method or as compared to a check area without application.*

**Keywords.** air-assist, application, disease, fungicide, nozzle tip, soybean, canopy penetration

# Nozzle and Carrier Application Effects on Control of Soybean Leaf Spot Diseases

H. Mark Hanna, Alison E. Robertson, W. Mark Carlton, and Robert E. Wolf[1]

## Introduction

Soybeans (*Glycine max L.*) are a major commodity crop grown on over 29 million hectare (72 million acres) in the United States. A large part of the cropland base in Iowa, 5 million hectare (11 to 13 million acres) annually, is devoted to soybean production. Although long term crop yield trends are upward, soybean yield increases have been more stagnant than corn, the common companion rotational crop, causing growers to question factors such as disease that might be slowing yield growth.

In late 2004 Asian Soybean Rust (*Phakopsora pachyrhizi*) was detected in the United States. Since then it has been detected sporadically late in the season in the Midwest including Iowa in late 2006. Because of the potential for yield loss as observed in other countries, grower concern has resulted in increased interest in this and other foliar leaf spot diseases that may be affecting yield. Midwestern U.S. agronomic row-crop growers are generally familiar and experienced with herbicide and insecticide application, but have very limited experiences in field application of fungicides. Growers customarily have existing sprayer equipment set up to apply systemic herbicides with relatively large droplets to reduce drift and carrier application rates of 94 to 143 L/ha (10 to 15 gal/acre) to minimize water transported and maximize the range of application area covered by an individual tank. Effective disease control is believed to be dependent on the amount of active ingredient deposited on and within the canopy and thus some recommended fungicide application methods include high spray pressure and hollow-cone nozzles. However, Egel and Harmon (2001) found neither nozzle type nor spray pressure affected Alternaria leaf blight severity of muskmelon. Thus nozzle type could be chosen based on growers' preference, and the purchase of high pressure spray equipment was not necessary.

Ozkan et al. (2006) found improved coverage and deposition with an air-assisted sprayer in the field within mature soybean canopy, although use of a canopy opener developed by Zhu et al. (2006) resulted in similar performance. Coverage and deposition from single-orifice, medium spray quality tips were generally greater than that from twin-orifice or hollow-cone tips producing coarse or fine spray quality (Ozkan et al., 2006). Wolf and Daggupati (2006) using a spray track compared various nozzle styles at 187 L/ha (20 gal/acre) and 16 km/h (10 mi/h) travel speed in laboratory and field trials. On average, single-orifice tips improved coverage slightly in the bottom canopy as compared to twin-orifice tips. Twin-orifice tips produced smaller droplets, but did not necessarily deposit more drops/cm$^2$ than single-orifice tips.

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Womac et al. (1992) examined characteristics of over-the-top, drop-nozzle, and air-assisted spray application in mature cotton. Increased spray rate (from 47 to 94 L/ha; 5 to 10 gal/acre) predominantly increased deposition and chemical efficacy under most conditions. Howard et al. (1994) measured penetration and deposition of air-assisted sprayers as compared to a conventional over-the-top sprayer in cotton. Although results among sprayers were comparable in the top of the canopy, in the middle of the canopy air-assisted sprayers had increased deposition.

### *Objective*

Because of the scarcity of information on foliar fungicide application techniques to Midwestern U.S. soybeans a field experiment was conducted to determine effects of nozzle type, carrier application, and application technique on droplet deposition within the crop canopy, foliar disease severity, and soybean yield. In particular, it was desired to compare the effects of: a) reduced carrier rate, b) larger droplet size common for herbicide application, and c) air-assisted sprayer with a spray application applying smaller droplet sizes at a greater than normal carrier application rate.

## Methods and materials

### *Treatments*

To increase the chance of applying fungicides at a location with foliar disease pressure, experimental plots were conducted at two sites, Iowa State University's Agricultural Engineering and Agronomy Farm near Boone in central Iowa and Iowa State University's McNay Farm near Chariton in south-central Iowa.

Five treatments were used at each site in 2005 and six treatments used in 2006 (table one). In addition to an unsprayed check treatment, each site had three application treatments common to both sites in both years. A relatively high 187 L/ha (20 gal/acre) application was made with two-orifice nozzle tips listed by the manufacturer as producing droplets in the larger size of the fine droplet spectrum (ASABE Standards, 2006). A lower application treatment, 112 L/ha (12 gal/acre), used two-orifice nozzle tips listed as also producing droplets in the larger end of the fine droplet spectrum. The third common application treatment used single-orifice nozzle tips commonly used in soybeans for systemic herbicide application (Turbo TeeJet, Spraying Systems, Wheaton, IL). Although the carrier application rate was relatively high (168 L/ha; 18 gal/acre) the droplet spectrum produced as listed by the manufacturer was in the smaller portion of the coarse droplet spectrum.

In 2005, a fourth application treatment at Boone was air-assisted with an air-curtain type sprayer applying at the high-rate application (187 L/ha (20 gal/acre) with two-orifice nozzle tips. Due to resource limitations in transporting this sprayer, the fourth application treatment at Chariton was instead an application with a Turbo TeeJet Duo nozzle (Spraying Systems, Wheaton, IL), new in the market that year. The nozzle consisted of two Turbo TeeJet tips producing a medium droplet spectrum according to the manufacturer while applying a 187 L/ha (20 gal/acre) application.

Table 1. Application treatments and operating conditions

| Treatment | Carrier application rate | | Nozzle | Pressure | | Speed | | Spray Quality | Boone | | Chariton | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L/ha | gal/acre | | kPa | psi | km/h | mi/h | | 2005 | 2006 | 2005 | 2006 |
| High-rate | 187 | 20 | 2-orifice 8004 | 276 | 40 | 9.6 | 6.0 | fine | X | X | X | X |
| Low-rate | 112 | 12 | 2-orifice 8003 | 207 | 30 | 10.3 | 6.4 | fine | X | X | X | X |
| Herbicide-style | 168 | 18 | 1-orifice, Turbo TeeJet 11003 | 276 | 40 | 8.0 | 5.0 | coarse | X | X | X | X |
| Air-assist | 187 | 20 | 2-orifice 8004 | 276 | 40 | 9.6 | 6.0 | fine | X | | | |
| Air-assist | 187 | 20 | Hollow-cone, JA-3 | 648 | 94 | 6.4 | 4.0 | fine | | X | | X |
| Turbo duo | 187 | 20 | 2-orifice, Turbo TeeJet Duo 11002 (2 tips) | 276 | 40 | 9.6 | 6.0 | medium | | | X | |
| Turbo Twinjet | 187 | 20 | 2-orifice Turbo 11004 | 276 | 40 | 9.6 | 6.0 | medium | | X | | X |
| Unsprayed check | | | | | | | | | X | X | X | X |

For the second year after consultation with the sprayer manufacturer, nozzle style on the air-assist treatment was changed to a hollow-cone tip operating at higher pressure, but at the same application rate (187 L/ha; 20 gal/acre). Also in the second year, the Turbo Duo treatment was replaced with a Turbo Twinjet tip, newly marketed for that product year by the manufacturer (Spraying Systems, Wheaton, IL). In this second year, both the air-assist and Turbo Twinjet treatments were used at both sites.

A 3-point-mounted sprayer with air-assist was used (Falcon Vortex, Jacto Manufacturing, Pompeia, Brazil) for all application treatments except the first year at Chariton. The sprayer had a 14-m (46-ft) boom with control over four boom sections. When the fan operated (only in the air-assist treatments), a curtain of air at speeds up to 100 km/h (62 mi/h) directed nozzle output down into the plant canopy. During the first year at Chariton, an older custom-built research sprayer with a 4.6-m (15-ft) long boom was used. Both sprayers had nozzles placed on 51-cm (20-in.) centers.

***Site details, field layout, and measurements***

Soybean row spacing at each site differed and reflected local planting practices. Row spacing at Boone was 76 cm (30 in.) in an east-west orientation and at Chariton was 38 cm (15 in.) in a north-south orientation. All treatments, including the unsprayed check were replicated in four field blocks at each location. Buffer areas at least one plot width wide were left unsprayed adjacent to each plot to avoid significant spray drift moving between plots. The number of nozzles used was adjusted so that full appropriate nozzle overlap was used across the width of each plot. At Boone individual plots were five rows wide (3.8 m; 12.5 ft) by 35 m (115 ft) long. A side section of the boom was used so that the tractor operating the sprayer did not travel through any plot areas. At Chariton during the first year, plots were eleven rows wide (4.2 m;13.8 ft) by 61 m (200 ft) long with the sprayer tractor driving down the centerline of each plot. At Chariton during the second year, plots were 4.2 m (13.8 ft) wide by 34 m (110 ft) long. A side section of the Falcon Vortex sprayer boom was used (as at Boone). Sprayer operation was always parallel to row direction except the second year at Chariton where sprayer operation was perpendicular (i.e. across) rows to accommodate field layout.

Measurements included droplet deposition on cards, foliar disease severity present on soybeans, and soybean yield. Measurement areas for deposition and foliar disease were at the bottom, middle, and top of the soybean plant canopy on eight soybean plants evenly spaced along a single measurement row within each plot. The measurement row location was selected to always be in the interior of the plot, but shifted off-center the first year at Chariton so as to be not directly adjacent to sprayer tractor wheel traffic or brushed by the tractor chassis.

Because of possible wet conditions from morning dew within the plant canopy, Kromekote paper (kkp) and dye were used rather than water-sensitive paper. Droplet collection cards (5 cm by 7.6 cm; 2 in. by 3 in.) constructed of Kromekote photographic paper were mounted with paper clips on individual leaf petioles inside the canopy before spraying. Pink sprayer dye (Tracer Hot Pink Foam Dye, Precision Labs, Northbrook, IL) was mixed into the spray solution at a concentration of 0.275%. Approximately one hour after spraying, cards were collected for later analysis. After droplet cards were scanned on a flatbed scanner, software (DropletScan; WRK of Arkansas, Lonoke, AR; and WRK of Oklahoma, Stillwater, OK; Devore Systems, Inc., Manhattan, KS) measured the number of droplets, droplet size, and area covered on each card.

Near each droplet card measurement area, 10 soybean trifoliate leaf samples were collected about two hours before spraying. Leaf samples were again collected near the same measurement sites almost three weeks later. Foliar disease severity (percent leaf area affected) was evaluated on each leaf sample to measure disease level immediately before and about three weeks after spraying. Because disease development is strongly influenced by environmental conditions after spraying rather than initial incidence of disease, measurement of disease severity on pre-sprayed leaves was omitted in the second year. Instead, with somewhat wetter field conditions during August post-spraying leaf samples were evaluated more intensively for severity of four specific diseases. Harvested soybean yield was measured at the end of the season by harvesting interior plot rows. Meteorology measurements (wind speed and direction, dry- and wet-bulb air temperature) were made several times during approximately 1.5 to 2.0 h of spray applications across all treatments at a location.

Tebuconazole fungicide (Folicur 3.6F, Bayer CropScience, Research Triangle Park, NC) was applied on all spray application treatments at an active ingredient rate of 113 g/ha (1.55 oz a.i./ac or product rate of 0.292 L/ha; 4 oz/ac).

***Statistical analysis***

Deposition, foliar disease, and yield data were statistically analyzed in analyses of variance to determine if observed treatment means were statistically different. Differences were measured at a 95% confidence level unless otherwise noted.

## Results and discussion

Field conditions at the time of spraying are listed in table 2.

Table 2. Field conditions during application

| Location | Date | Air temp. | | Relative humidity | Wind direction | Wind speed | | Soybean growth stage |
|---|---|---|---|---|---|---|---|---|
| | | ˚C | ˚F | % | | km/h | mi/h | |
| Boone | 7-27-05 | 24 | 75 | 38 | NNW | 4.8 – 9.6 | 3 – 6 | early R4 |
| Chariton | 7-29-05 | 29 | 85 | 44 | SSW | 3.2 – 8.0 | 2 – 5 | late R3 |
| Boone | 8-11-06 | 26 | 78 | 53 | ESE | 6.4 – 8.0 | 4 - 5 | R5 |
| Chariton | 8-15-06 | 27 | 81 | 23 | S | 1.6 – 4.8 | 1 – 3 | R5 |

***Deposition***

Software used to measure droplets failed midway during analysis of the third set of replicated plots at the second site in the second year. Discussions with the software developer and repeated attempts at scanning cards failed to resolve the problem. Because only 68% of cards had been able to be measured, for the second year at Chariton treatment means with three (all high-rate, low-rate, and herbicide-style; bottom and middle of air-assist) or two (all Turbo Twinjet, air-assist top) replications are reported as additional information but without statistical analysis.

Deposition measurements from droplet cards near the bottom of the soybean leaf canopy are shown in table 3. Spray droplet volume diameters are listed for the droplet size below which 10% (VD0.1), 50% (VD0.5), and 90% (VD0.9) of the spray volume was being applied.

Table 3. Droplet measurements from collection cards near bottom of leaf canopy

| | Area | | Volume diameter, µm | | |
|---|---|---|---|---|---|
| Site/treatment | % | Drops/$cm^2$ | 0.5[a] | 0.1[b] | 0.9[c] |
| Boone, 2005 | | | | | |
| High-rate | 1.73 | 28.5 | 225 | 128 | 379 |
| Low-rate | 0.75 | 13.8 | 255 | 120 | 379 |
| Herbicide-style | 1.28 | 15.3 | 354 | 143 | 558 |
| Air-assist | 1.10 | 18.3 | 268 | 130 | 424 |
| $LSD_{\alpha=0.05}$[d] | NS[e] | NS | 79 | NS | 51 |
| Chariton, 2005 | | | | | |
| High-rate | 6.40 | 85.0 | 307 | 137 | 497 |
| Low-rate | 1.78 | 31.0 | 265 | 125 | 414 |
| Herbicide-style | 3.95 | 41.8 | 390 | 152 | 610 |
| Turbo duo | 3.53 | 25.0 | 350 | 166 | 527 |
| $LSD_{\alpha=0.05}$ | NS | 10%[f] | 55 | 10% | 47 |
| Boone, 2006 | | | | | |
| High-rate | 0.80 | 7.8 | 333 | 181 | 493 |
| Low-rate | 1.28 | 19.0 | 262 | 159 | 394 |
| Herbicide-style | 1.65 | 15.0 | 401 | 223 | 563 |
| Air-assist | 1.10 | 32.3 | 183 | 115 | 285 |
| Turbo Twinjet | 1.85 | 19.3 | 326 | 189 | 494 |
| $LSD_{\alpha=0.05}$[d] | NS | NS | 57 | 10%[f] | 72 |
| Chariton, 2006 | | | | | |
| High-rate | 1.03 | 15.3 | 299 | 177 | 613 |
| Low-rate | 1.93 | 30.0 | 249 | 139 | 418 |
| Herbicide-style | 2.37 | 24.7 | 300 | 163 | 614 |
| Air-assist | 4.10 | 32.3 | 263 | 125 | 456 |
| Turbo Twinjet | 3.00 | 36.5 | 319 | 169 | 512 |

[a]Volume median diameter; 50% of spray volume is contained in droplets smaller than this size
[b]VD0.1; 10% of spray volume is contained in droplets smaller than this size
[c]VD0.9; 90% of spray volume is contained in droplets smaller than this size
[d]Least significant difference at 95% confidence level for a card position at a specific location
[e]No significant difference
[f]Differences not significant at 95% confidence level, but are significant at reduced 90% confidence level

In 2005 at the Boone location, the coarser droplet spectrum produced by nozzles in the herbicide-style treatment produced larger VD0.5 and VD0.9 values as expected. At Chariton, VD0.5 and VD0.9 droplet sizes for the herbicide-style treatment were also larger than the high-rate and low-rate treatments. The Turbo Duo produced a medium droplet spectrum as expected at VD0.5 and VD0.9

but had numerically the largest droplet size at VD0.1. Differences among treatments were statistically significant at a reduced 90% confidence level for VD0.1 measurements.

In 2006 at the Boone site, droplet size differences were slightly more pronounced, particularly at VD0.5 with statistically larger droplets at the high-rate than low-rate treatments along with expected differences related to spray droplet quality. Again at VD0.1 differences were only significant at a reduced 90% confidence level.

Despite using eight sample measurement sites within each plot, deposition variability between plots precluded detecting statistical differences in percent area covered or droplet number. The high-rate treatment at Chariton did have statistically more drops/$cm^2$ at a reduced confidence level of 90%.

Deposition measurements in the middle of the leaf canopy are shown in table 4. In 2005 at Boone, for the herbicide-style treatment VD0.5 was larger than for the low-rate treatment and VD0.9 was larger than all other spray treatments. At Chariton, both VD0.5 and VD0.9 were largest for the herbicide-style treatment and the medium droplet spectrum of Turbo duo treatment had larger values than the low-rate treatment. VD0.1 (at Chariton) of both the herbicide-style and Turbo duo treatments was larger than that of finer droplet spectrum produced in the low- and high-rate treatments.

In 2006 at Boone, herbicide-style, Turbo Twinjet, and high-rate treatments had larger droplets at VD0.5, VD0.9, and VD0.1 than did the low-rate and air-assist treatments.

In 2006 at Boone the air-assist treatment applied more drops/$cm^2$. Similar to canopy bottom measurement, other statistical differences were not detected in percent area covered or drops/$cm^2$.

Table 4. Droplet measurements from collection cards near middle of leaf canopy

| Site/treatment | Area % | Area Drops/cm² | Volume diameter, µm 0.5[a] | Volume diameter, µm 0.1[b] | Volume diameter, µm 0.9[c] |
|---|---|---|---|---|---|
| Boone, 2005 | | | | | |
| High-rate | 6.48 | 68.5 | 317 | 145 | 483 |
| Low-rate | 3.73 | 54.0 | 250 | 132 | 401 |
| Herbicide-style | 4.85 | 40.5 | 378 | 153 | 604 |
| Air-assist | 7.75 | 72.5 | 321 | 168 | 483 |
| $LSD_{\alpha=0.05}$[d] | NS[e] | NS | 70 | 10%[f] | 88 |
| Chariton, 2005 | | | | | |
| High-rate | 8.13 | 91.5 | 335 | 150 | 531 |
| Low-rate | 4.25 | 56.0 | 302 | 143 | 464 |
| Herbicide-style | 10.65 | 69.3 | 461 | 198 | 708 |
| Turbo duo | 7.75 | 56.0 | 375 | 180 | 551 |
| $LSD_{\alpha=0.05}$ | NS | NS | 57 | 30 | 82 |
| Boone, 2006 | | | | | |
| High-rate | 3.38 | 27.0 | 355 | 198 | 533 |
| Low-rate | 3.85 | 47.8 | 277 | 153 | 437 |
| Herbicide-style | 7.88 | 46.0 | 399 | 199 | 613 |
| Air-assist | 5.93 | 116.0 | 230 | 132 | 348 |
| Turbo Twinjet | 10.55 | 62.8 | 392 | 205 | 585 |
| $LSD_{\alpha=0.05}$[d] | NS | 44.8 | 74 | 31 | 84 |
| Chariton, 2006 | | | | | |
| High-rate | 4.57 | 46.7 | 321 | 174 | 489 |
| Low-rate | 4.97 | 66.3 | 261 | 153 | 425 |
| Herbicide-style | 5.80 | 32.0 | 400 | 200 | 621 |
| Air-assist | 3.63 | 35.3 | 266 | 134 | 581 |
| Turbo Twinjet | 9.40 | 87.0 | 349 | 182 | 543 |

[a]Volume median diameter; 50% of spray volume is contained in droplets smaller than this size
[b]VD0.1; 10% of spray volume is contained in droplets smaller than this size
[c]VD0.9; 90% of spray volume is contained in droplets smaller than this size
[d]Least significant difference at 95% confidence level for a card position at a specific location
[e]No significant difference
[f]Differences not significant at 95% confidence level, but are significant at reduced 90% confidence level

Deposition values at the top of the leaf canopy are shown in table 5. At the Boone site, both VD0.5 and VD0.9 values were greatest for the herbicide-style treatment, intermediate for the high-rate and air-assist treatments, least for the low-rate treatment. VD0.1 values were greatest for the herbicide-style and air-assist treatments, intermediate for the high-rate treatment and least for the low-rate treatment.

At the Chariton site, VD0.5 for the herbicide-style treatment was greater than for the low- and high-rate treatments. Differences among treatments were statistically significant at a reduced 90% confidence level for VD0.9 measurements.

In 2006 at Boone, droplet sizes were statistically larger for the herbicide-style, Turbo Twinjet, and high-rate applications than the low-rate and air-assist applications (similar to mid- and bottom-canopy measurements).

In 2005 at Boone, the air-assist and high-rate treatments had more drops/cm$^2$ and greater area covered than low-rate and herbicide-style treatments.

Table 5. Droplet measurements from collection cards near top of leaf canopy

| | Area | | Volume diameter, µm | | |
|---|---|---|---|---|---|
| Site/treatment | % | Drop/cm$^2$ | 0.5[a] | 0.1[b] | 0.9[c] |
| Boone | | | | | |
| High-rate | 21.18 | 156.3 | 395 | 181 | 637 |
| Low-rate | 9.53 | 115.5 | 302 | 147 | 460 |
| Herbicide-style | 16.68 | 86.5 | 470 | 200 | 710 |
| Air-assist | 24.23 | 148.8 | 394 | 202 | 594 |
| $LSD_{\alpha=0.05}$[d] | 4.52 | 32.7 | 32 | 16 | 66 |
| Chariton | | | | | |
| High-rate | 18.23 | 155.0 | 445 | 205 | 725 |
| Low-rate | 14.65 | 100.3 | 400 | 192 | 634 |
| Herbicide-style | 20.25 | 90.0 | 530 | 228 | 806 |
| Turbo duo | 12.90 | 62.3 | 472 | 234 | 691 |
| $LSD_{\alpha=0.05}$ | NS[e] | NS | 84 | NS | 10%[f] |
| Boone | | | | | |
| High-rate | 16.28 | 95.0 | 442 | 224 | 645 |
| Low-rate | 9.33 | 95.8 | 339 | 175 | 503 |
| Herbicide-style | 18.30 | 83.8 | 499 | 238 | 707 |
| Air-assist | 10.07 | 108.3 | 310 | 169 | 486 |
| Turbo Twinjet | 18.43 | 82.3 | 478 | 239 | 693 |
| $LSD_{\alpha=0.05}$[d] | NS | NS | 68 | 32 | 101 |
| Chariton | | | | | |
| High-rate | 10.17 | 75.3 | 386 | 198 | 574 |
| Low-rate | 14.33 | 129.3 | 347 | 174 | 542 |
| Herbicide-style | 8.37 | 44.0 | 439 | 220 | 651 |
| Air-assist | 2.85 | 58.5 | 219 | 129 | 329 |
| Turbo Twinjet | 15.60 | 112.5 | 405 | 202 | 613 |

[a]Volume median diameter; 50% of spray volume is contained in droplets smaller than this size
[b]VD0.1; 10% of spray volume is contained in droplets smaller than this size
[c]VD0.9; 90% of spray volume is contained in droplets smaller than this size
[d]Least significant difference at 95% confidence level for a card position at a specific location
[e]No significant difference
[f]Differences not significant at 95% confidence level, but are significant at reduced 90% confidence level

Regarding deposition, VD0.5 and VD0.9 values for application treatments generally followed expected manufacturer suggested rankings from coarse to medium to fine droplet sizes. Expected ranking was less apparent for VD0.1 values. An exception in 2006 occurred when droplets from the high-rate treatment were grouped statistically (at Boone) with the herbicide-style and Turbo Twinjet treatments (this trend also was observed in means at Chariton). Percentage area covered and drops/$cm^2$ were not statistically different with two exceptions. In 2005 at the top of the plant canopy at the Boone site air-assist and high-rate applications had greater coverage. In 2006 in the middle of the plant canopy at Boone the air-assist application deposited greater drops/$cm^2$.

In a separate analysis, all data was pooled (i.e., all three canopy locations) within each site and year. In 2005, percentage area covered and drops/$cm^2$ were statistically greater at the top of the canopy than at the middle or bottom at both sites. Mean top coverage was 18% at Boone and 17% at Chariton, but ranged from 1 to 8% mean coverage at the bottom or middle canopy positions depending on site and canopy position. At the Boone site percentage area covered and drops/$cm^2$ were statistically greater at the middle than at the bottom of the canopy. At the Boone site the air-assist and high-rate treatments had greater percentage coverage and drops/$cm^2$ than low-rate and herbicide-style treatments, although at Chariton no statistical difference among treatments was detected.

Using pooled data in 2006 at Boone, percentage area covered and drops/$cm^2$ were again statistically different in each of the three parts of the plant canopy. The air-assist treatment deposited statistically more drops/$cm^2$ than other treatments, but the Turbo Twinjet treatment had statistically greater percentage coverage than the low-rate or air-assist treatments. The trend toward greater percentage coverage by the Turbo Twinjet was also noted at Chariton.

### *Efficacy of application treatments and yield*

Leaf disease severity in 2005 immediately before fungicide applications and almost three weeks after application are shown in table 6. Dry environmental conditions during the period were not conducive for the development of soybean foliar diseases. Although brown spot (*Septoria glycines*) and frogeye leaf spot (*Cercospora sojina*) were present at both sites, low disease pressure precluded detecting any differences among application treatments or with the unsprayed check.

With more frequent August precipitation events in 2006 (than 2005) foliar soybean disease pressure was greater, however differences among application treatments were not able to be detected except at a lower 90% confidence level (tables 7 and 8). At this reduced confidence level, percentage brown spot was less at the bottom of the canopy in the Turbo Twinjet application than in the high-rate application. Also at this confidence level in mid-canopy, the unsprayed check had greater incidence of cercospora leaf blight *(Cercospora kikuchii)* than did sprayed treatments. Egel and Harmon (2001) also found fungicide application method had little affect on Alternaria leaf blight disease severity.

Table 6. Soybean leaf disease severity in bottom, middle, and top of leaf canopy before and after spraying, 2005[a]

| | Before spraying | | | After spraying | | |
|---|---|---|---|---|---|---|
| Site/treatment | Bottom | Middle | Top | Bottom | Middle | Top |
| Boone | | | | | | |
| High-rate | 0.97 | 0.05 | 0.00 | 0.58 | 0.00 | 0.00 |
| Low-rate | 1.28 | 0.16 | 0.02 | 0.64 | 0.00 | 0.00 |
| Herbicide-style | 0.75 | 0.00 | 0.00 | 0.61 | 0.23 | 0.00 |
| Air-assist | 0.77 | 0.09 | 0.00 | 0.81 | 0.03 | 0.00 |
| No spray | 1.05 | 0.06 | 0.02 | 0.75 | 0.41 | 0.00 |
| $LSD_{\alpha=0.05}$[b] | NS[c] | NS | NS | NS | NS | NS |
| Chariton | | | | | | |
| High-rate | 0.78 | 0.20 | 0.02 | 0.92 | 0.19 | 0.00 |
| Low-rate | 0.97 | 0.17 | 0.03 | 0.64 | 0.13 | 0.00 |
| Herbicide-style | 1.03 | 0.16 | 0.00 | 0.58 | 0.09 | 0.05 |
| Turbo duo | 0.50 | 0.27 | 0.00 | 0.84 | 0.14 | 0.00 |
| No spray | 0.66 | 0.33 | 0.00 | 0.69 | 0.09 | 0.00 |
| $LSD_{\alpha=0.05}$ | NS | NS | NS | NS | NS | NS |

[a]Severity scale:
0 = no disease
0.5 = few spots
1 = <15% of leaf area with disease
2 = 15 – 24% leaf area with disease

[b]Least significant difference at 95% confidence level for a leaf position at a specific location

[c]Differences are not statistically significant

Table 7. Percentage brown spot and frogeye leaf disease severity[a] in bottom, middle, and top of leaf canopy, 2006

| | Brown spot | | | Frogeye | | |
|---|---|---|---|---|---|---|
| Site/treatment | Bottom | Middle | Top | Bottom | Middle | Top |
| Boone | | | | | | |
| High-rate | 10.32 | 0.44 | 0.00 | 0.59 | 1.35 | 1.10 |
| Low-rate | 19.35 | 0.00 | 0.00 | 0.41 | 1.25 | 1.38 |
| Herbicide-style | 12.26 | 2.81 | 0.00 | 0.12 | 1.00 | 0.97 |
| Air-assist | 9.90 | 0.00 | 0.00 | 0.30 | 1.44 | 1.41 |
| Turbo Twinjet | 11.65 | 0.00 | 0.00 | 0.44 | 0.97 | 0.60 |
| No spray | 18.04 | 0.00 | 0.00 | 0.66 | 0.91 | 0.97 |
| $LSD_{\alpha=0.05}$[b] | NS[c] | NS | NS | NS | NS | NS |
| Chariton | | | | | | |
| High-rate | 13.25 | 0.00 | 0.00 | 0.92 | 1.04 | 2.04 |
| Low-rate | 3.13 | 0.00 | 0.00 | 0.64 | 2.30 | 0.83 |
| Herbicide-style | 3.32 | 0.13 | 0.00 | 0.58 | 1.07 | 1.01 |
| Air-assist | 5.38 | 2.32 | 0.00 | | 1.00 | 1.25 |
| Turbo Twinjet | 1.21 | 0.00 | 0.00 | 0.84 | 0.92 | 0.33 |
| No spray | 8.41 | 1.85 | 0.00 | 0.69 | 2.10 | 1.51 |
| $LSD_{\alpha=0.05}$ | 10%[d] | NS | NS | NS | NS | NS |

[a]Disease severity = mean percentage leaf area with disease (N=32 at each location and treatment)
[b]Least significant difference at 95% confidence level for a leaf position at a specific location
[c]Differences are not statistically significant
[d]Differences not significant at 95% confidence level, but are significant at reduced 90% confidence level

Table 8. Downy mildew severity[a] and incidence[b] of cercospora leaf blight in bottom, middle, and top of leaf canopy, 2006

| | Downy mildew | | | Cercospora leaf blight | | |
|---|---|---|---|---|---|---|
| Site/treatment | Bottom | Middle | Top | Bottom | Middle | Top |
| Boone | | | | | | |
| High-rate | 0.00 | 0.06 | 0.28 | 0.00 | 0.03 | 0.32 |
| Low-rate | 0.00 | 0.13 | 0.13 | 0.00 | 0.00 | 0.25 |
| Herbicide-style | 0.00 | 0.03 | 0.13 | 0.00 | 0.00 | 0.25 |
| Air-assist | 0.00 | 0.19 | 0.25 | 0.00 | 0.00 | 0.06 |
| Turbo Twinjet | 0.00 | 0.38 | 0.44 | 0.00 | 0.00 | 0.28 |
| No spray | 0.00 | 0.13 | 0.47 | 0.00 | 0.22 | 0.32 |
| $LSD_{\alpha=0.05}$[c] | NS[d] | NS | NS | NS | 10%[e] | NS |
| Chariton | | | | | | |
| High-rate | 0.00 | 1.50 | 0.71 | 0.00 | 0.21 | 0.34 |
| Low-rate | 0.13 | 0.21 | 0.71 | 0.00 | 0.00 | 0.17 |
| Herbicide-style | 0.00 | 0.13 | 0.57 | 0.00 | 0.07 | 0.13 |
| Air-assist | 0.00 | 0.44 | 1.00 | 0.00 | 0.00 | 0.07 |
| Turbo Twinjet | 0.00 | 0.54 | 2.08 | 0.00 | 0.00 | 0.29 |
| No spray | 0.00 | 0.28 | 0.32 | 0.03 | 0.10 | 0.22 |
| $LSD_{\alpha=0.05}$ | NS | NS | NS | NS | NS | NS |

[a]Disease severity = mean percentage leaf area with disease (N=32 at each location and treatment)
[b]Incidence equals fraction (0 to 1.00) of leaves with cercospora leaf blight
[c]Least significant difference at 95% confidence level for a leaf position at a specific location
[d]Differences are not statistically significant
[e]Differences not significant at 95% confidence level, but are significant at reduced 90% confidence level

Perhaps because disease pressure among treatments was limited, harvested soybean yields and moisture content at harvest (as a gauge of maturity) were also statistically equivalent across all application treatments and the unsprayed check (table 9).

Table 9. Soybean yields (adjusted to 13%) and moisture content at harvest for fungicide application treatments

| Location/treatment | Yield, bu/ac | | Moisture content, % | |
|---|---|---|---|---|
| | 2005 | 2006 | 2005 | 2006 |
| Boone | | | | |
| High-rate | 64.9 | 48.6 | 13.1 | 13.0 |
| Low-rate | 61.2 | 46.5 | 12.9 | 14.6 |
| Herbicide-style | 62.4 | 47.7 | 12.9 | 14.9 |
| Air-assist | 62.8 | 46.5 | 12.9 | 14.1 |
| Turbo Twinjet | | 49.9 | | 13.7 |
| No spray | 62.7 | 47.0 | 12.9 | 13.9 |
| $LSD_{\alpha=0.05}$[a] | NS[b] | NS | NS | NS |
| Chariton | | | | |
| High-rate | 49.2 | 53.0 | 15.0 | 13.6 |
| Low-rate | 45.0 | 53.7 | 14.8 | 13.7 |
| Herbicide-style | 48.5 | 51.6 | 15.4 | 13.6 |
| Air-assist | | 54.1 | | 13.8 |
| Turbo duo | 46.3 | | 15.2 | |
| Turbo Twinjet | | 53.3 | | 13.6 |
| No spray | 43.5 | 53.3 | 14.8 | 13.7 |
| $LSD_{\alpha=0.05}$[b] | NS | NS | NS | NS |

[a]Least significant difference at 95% confidence level for a leaf position at a specific location
[b]Differences are not statistically significant

## Conclusions

Within the range of conditions encountered at two field sites, data support the following conclusions:

Deposition:

- VD0.5 and VD0.9 values for application treatments generally followed expected manufacturer suggested rankings from coarse to medium to fine droplets. Expected ranking was less apparent for VD0.1 values. An exception was in year two when droplet sizes of the high-rate (187 L/ha; 20 gal/acre) treatment were similar to those of the herbicide-style and Turbo Twinjet treatment.
- Percentage area covered and drops/cm$^2$ were not statistically different among treatments except at top of the plant canopy (year one) and middle of the plant canopy (year two, drops/cm$^2$) at the Boone site. Pooling data from the top-, middle-, and bottom-canopy locations, the air-assist and high-rate treatments had greater percentage area coverage and drops/cm$^2$ at Boone the first year. In the second year at Boone although the air-assist treatment deposited greater drops/cm$^2$, the Turbo Twinjet treatment had greater percentage coverage than the low-rate and air-assist treatments. Although smaller droplets often produced increased drops/cm$^2$, in the second year percentage coverage for medium-to-coarse droplets was numerically greater than most fine droplet treatments.
- When all data was pooled (all canopy locations) within each site and year, percentage area covered and drops/cm$^2$ were statistically greater at the top of the canopy (15 - 18% coverage)

than at the middle or bottom (1 – 8% coverage). At the Boone site percentage area covered and drops/$cm^2$ were statistically greater at the middle than at the bottom of the canopy both years.

Foliar disease and yield:

- Foliar disease pressure was light, perhaps due to environmental conditions, and differences were not detected except at a reduced (90%) level of confidence. At this level, all fungicide application treatments controlled disease equally.
- Soybean yield was not affected by application treatments as compared to the unsprayed check. In order to observe application within dense plant canopy, application was delayed until later reproductive stages in August (i.e. yield effect was not tested by earlier application).

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